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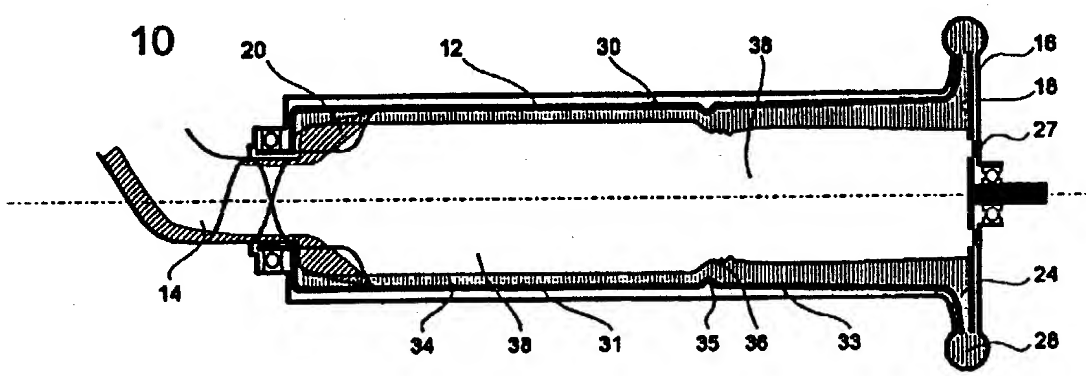

(57) Abstract

The invention relates to an apparatus and a process for separating a gas from a mixture containing liquid and gas, especially in connection with pumping. The apparatus comprises a centrifuge (12) with a fluid inlet (14) at one end, a liquid outlet (28) at the opposite end and a gas outlet (27) from the center (38) of said centrifuge. An inner wall of said centrifuge forms a gas separation part (30) between said fluid inlet (14) and said liquid outlet (28). The gas separation part is divided into first and second separation sections (31, 33) by circumferential transition means (35) extending inwardly towards the center of the centrifuge for effecting a hydraulic jump in the axial flow of the fluid.

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Apparatus and process for separating a mixture of gas and liquid

The present invention relates to an apparatus and a process for separating a gas such as air from a liquid such as water, solvents, reagents, oil, suspensions, etc., especially in connection with pumping said liquid.

In many cases gas enclosed or generated in a fluid causes problems. For example, when pumping fluids containing gas with a conventional centrifugal pump, the gas disturbs the pumping; air enclosed in reagents and solvents may disturb a chemical process; air and gas bubbles in the fuel and/or oil feed may cause disturbances in combustion engines; the forming of paper requires suspensions essentially free of gas bubbles, etc.

Pumps, which are able to separate gas from a fluid to be pumped are well known as such, but the objective of such pumps is normally just to remove a sufficient portion of the gas to enable regular pumping. Centrifuges of various designs have been used for removing gas from liquids, but a common problem in such devices is that gas will often be re-mixed into the degassed liquid due to a turbulence in the liquid flow prior to the discharging of the liquid.

Among the prior art patents relating to centrifugal means for separating gas from fluids, or for pumping fluids containing or developing vapor, US 2,278,397, US 3,856,483, US 4,908,048, GB 1257173 and WO 9323135 may be mentioned.

Many of the prior art devices include a centrifuging drum, where the liquid flows in a spiral flow along the wall of the drum and the gas is separated into a void gas column in the center of the apparatus, whereafter the degassed liquid may be separately discharged.

The present invention relates to improvements in known gas separation devices and especially to an improvement in the gas separation pump disclosed in the same applicant's co-pending patent application PCT/FI94/00578. The invention will, however, also improve the operation of other centrifugal gas separation devices.

It is known (e.g. from B.S. Massey; Mechanics of Fluids, 2nd Edition, Van Norstrand Reinhold Co. Ltd. London 1971, pp 334 to 359) that a fluid flowing in an open channel can flow in two distinct modes, either tranquil or rapid. The flow mode of the fluid is determined by the Froude number according to the equation

$$Fr = u/(h \times g)^{1/2}$$

where Fr is the Froude number, u is the flow speed, h is the layer thickness and g is the force of gravitation. If $Fr>1$ the flow is rapid and if $Fr<1$ the flow is tranquil. There is no intermediate flow speed, which means that if a rapid flow is slowed down, a hydraulic jump will take place at the transition between rapid and tranquil flow. This phenomenon is known in the art of fluid flow in open channels, etc. and it is utilized among others in water power stations. It has, however, not so far been utilized in connection with the centrifugal separation of gases from liquids nor in the pumping of liquids.

If the liquid flow in the gas separation drum of a centrifugal gas separation device is rapid at any stage, it should preferably be transformed into a tranquil state before being removed from the device in order to avoid excessive turbulence and re-entraining of gas into the liquid at the outlet end. This is particularly important in cases, where the objective is to produce a liquid essentially free of gas, as is the case for instance in the air-free pumping of back-water of a paper machine, in certain chemical processes, etc.

In many prior art pumps the flow is either so slow, i.e. the capacity of the pump so low, that tranquil flow prevails, or the need for a gas-free state is so secondary, that a rapid flow at the outlet can be accepted. In such pumps there occurs no hydraulic jump.

In pumps with a high flow rate and a high demand for having a gas-free liquid, a hydraulic jump will obviously occur at some stage. The exact place of the hydraulic jump varies with the flow conditions and the shape of the air separation drum, and sometimes the hydraulic jump may be instable, causing instability in the function of the pump.

The gas separation pump according to the above mentioned co-pending patent application PCT/FI94/00578 has an annular shoulder at the outlet end of the rotor at the transition point where the gas separation part ends and the wider pumping zone starts. This annular shoulder will cause an upstream damming of the liquid layer on the separation surface and there is no subsequent region for the settling of a tranquil flow. The shoulder will, in fact, function as intended only if the flow prior to the shoulder is in the tranquil mode. This means that in an apparatus with a rapid flow, the hydraulic jump will have occurred prior to said shoulder in an uncontrolled way, as in other prior art devices.

The object of the present invention is to improve the function of known processes and apparatuses in order to provide stable conditions when separating a gas from a liquid at a high flow rate. The object of the invention is especially to control the position and form of the hydraulic jump in a gas separation device having a rapid flow of fluid.

The unique features of the present invention are defined in the appended claims.

The present invention thus relates to an apparatus for separating gas enclosed in a fluid. Said apparatus comprises a centrifuge of a circular cross-section having at one end thereof an inlet for a mixture of liquid and gas and at the opposite end an outlet for separated liquid. Said apparatus further comprises a gas outlet from the center of said centrifuge. The wall of the centrifuge forms a gas separation part for the essentially complete separation of gas from the mixture of gas and liquid. The centrifuge wall is equipped with circumferential transition means for causing the liquid flow to change mode of flow from rapid to tranquil via a hydraulic jump. Said gas separation part is divided into a first section for rapid axial flow with a Froude number > 1 and a second section for tranquil flow with a Froude number < 1 by means of said transition means.

The gas separation part is preferably of an elongated tubular construction and the second separation section should have a length which is sufficient for allowing any gas bubbles, which might be mixed into the liquid at the hydraulic jump, to be removed and for the liquid flow to attain a tranquil mode of flow. It is preferred to place the transition means on the centrifuge wall in such a position that it divides the gas separation part so that the axial length of the gas separation part to the axial length of the second separation part is between 1:0.1 and 1:0.9, preferably between 1:0.2 and 1:0.8, most preferably between about 1:0.4 to 1:0.6.

It is important that the transition means only provides a transition in the flow mode but does not cause any substantial damming of the flow along the gas separation part. Thus, the transition means preferably has a streamlined form in the upstream direction and rises above the level of the first gas separation part to a height which is no more than about 1/20, preferably no more than about 1/40 of the diameter of the first gas separation part.

The liquid outlet end of the centrifuge preferably comprises a pumping wheel for pumping the separated liquid.

The present invention also relates to a process for separating a liquid from a relatively lighter gas such as air, and providing liquid essentially free of gas and gas essentially free of liquid. The process preferably comprises pumping the liquid separately from said gas.

In the preferred embodiment the steps of said process comprise bringing said mixture into rotation in a gas separation part of a tubular centrifuge for causing said mixture to flow towards a large gas separation surface formed by a wall of said centrifuge; causing said rotating mixture to flow in a thin fluid layer along said gas separation surface in a rapid flow (Fr>1); retarding said rapid flow on said gas separation surface to a tranquil flow mode (Fr<1) by means of transition means on said gas separation surface; causing said gas to separate from said liquid due to said rotation of said mixture to form a gas column at the center of said gas separation part; causing the separated liquid to flow, in a tranquil mode of flow (Fr<1), along said gas separation surface to the rotating outlet end of the centrifuge; and discharging said liquid from said outlet end and discharging said gas from the center of the centrifuge.

The tranquil flow of degassed liquid is preferably directed into a pumping wheel connected to said outlet end and rotating with said centrifuge. Said liquid will form a liquid ring in said pumping wheel and can be discharged centrifugally at pumping pressure.

The present invention will be described in greater detail in the following while referring to the drawings, wherein:

Fig. 1 shows a section of a gas separation pump according to the preferred embodiment of the invention seen from the side,

Fig. 2 shows a section of a chemical reactor including another embodiment of a gas separator according to the invention,

Figs 3a, b and c show alternative embodiments of transition means according to the invention, and

Fig. 4 shows a further embodiment of a gas separator according to the invention.

In the preferred embodiment of the invention according to Fig. 1 the gas separation pump indicated by a general reference numeral 10 comprises a rotor or centrifuge 12, a fluid inlet 14 for a mixture of gas and liquid at one end and, at the opposite end, an outlet 28 for liquid which is essentially free of gas. The fluid inlet 14 as well as the liquid outlet 28 are preferably of a spiral configuration. The center 38 of the centrifuge 12 comprises a discharge means for separated gas.

At the inlet end of said centrifuge 12 there is a set of blades 20 for facilitating the rotation of the fluid as it enters the centrifuge 12. At the outlet end the centrifuge 12 enlarges into a pumping wheel 24 and ends in a bottom plate 18, both pumping wheel 24 and bottom plate 18 rotating with the centrifuge 12. The pumping wheel 24 is preferably provided with blades (not shown) and it is enclosed in a stationary pump housing 16 including a stationary peripheral liquid outlet 28.

The central portion of the centrifuge 12 is formed into an elongated tubular gas separation part 30, the wall of which provides a large gas separation surface. The gas separation part 30 should be sufficiently long, for allowing sufficient time and space for the fluid fed through inlet 14 into the rotating centrifuge to settle into a thin fluid layer 34 and to allow the enclosed gas to separate therefrom. The gas

separation part 30 should also be dimensioned to allow any sprays resulting from the action of blades 20 at the inlet end to settle at said separation surface and to allow any gas enclosed during this settling to separate.

The gas separation part 30 is split into a first separation section 31 and a second separation section 33 by means of an annular transition ring 35 protruding from the gas separation surface.

During use a thin fluid layer 34 of the mixture forms on the surface of the first separation section 31. Due to the action of the blades 20, the fluid layer is accelerated to have approximately the same peripheral speed as the centrifuge 12. Due to the rotation of the centrifuge 12, the fluid layer 34 is caused to rotate rapidly in said separation part 30 and is subject to a centrifugal force, which causes the lighter gas bubbles in the fluid mixture to rise to the surface of the mixture and from there towards the center of the gas separation pump 10, forming a central gas column 38. The gas may be discharged either through a gas outlet 27 in the pump housing 16 or through the rotor shaft in either outlet or inlet direction.

The rotating fluid ring 34 will also be accelerated axially, the axial flow speed being approximately equal to the speed difference between the centrifuge and the inlet flow. This axial velocity will normally lie in the rapid flow range. When the flow reaches the transition ring 35, the ring causes the flow to change direction, diverting it towards the center of the apparatus, and a hydraulic jump occurs. The hydraulic jump is indicated in Fig. 1 by the reference numeral 36. As a consequence, the axial speed of the fluid layer 34 slows down to a tranquil mode of flow, whereby $Fr < 1$ (Fr = the Froude number). The flow energy, however, will be largely conserved. The degree of energy conservation is dependent, among others, on the smoothness of the jump.

Towards the outlet end 22 of the centrifuge, after said transition ring 35, the separation part 30 at said second separation section 33 is preferably slightly conical. At the outlet end the diameter of the centrifuge 12 enlarges smoothly into a pumping wheel 24. During use of the apparatus the liquid at said outlet end is caused to retain its depth, so that a tranquil mode of axial flow is maintained. The liquid, which is now essentially free of gas, forms a rotating liquid ring in the pump housing surrounding the pumping wheel 24. The liquid is finally pressed out through liquid discharge pipe 28 which extends as a stationary spiral around the periphery of the pump housing 16.

The depth of liquid ring in pump housing 16 automatically adjusts, within certain limits, to the flow of entering fluid so that a pumping pressure sufficient for pumping the liquid forward is obtained. By adjusting the rotational speed of the centrifuge 12, the depth of the water ring can be adjusted according to the flow of incoming fluid mixture and the required pumping pressure.

Even if the stream-lined bump-like shape of the annular ring 35, extending radially about 2 to 10 % of the radius of the centrifuge toward the centre of the gas separating part, followed by a slightly conical separation section 33, as represented by Fig. 1, is considered the most preferred embodiment of the invention, the geometrical shape of the transition means is not limited to this form. The invention functions also if the transition means is shaped like a step or consists of several bumps arranged circumferentially around the gas separation surface.

After the hydraulic jump, the depth of the water ring is maintained such, that the tranquil state of axial flow is maintained. Maintaining the tranquil or close to tranquil axial flow may be facilitated by disturbing the flow by means

of bumps or other obstacles, so that every acceleration, increasing the Froude number to Fr >1 will cause minor hydraulic jumps, impeding acceleration.

In the embodiment of Fig. 1 the first and the second separation sections 31, 33 are of an approximately similar length. Depending on the characteristics of the fluid to be degassed and on the desired operational parameters, it may be favorable to place the transition means closer to the inlet or closer to the outlet end of the separation part. It is, however, important to provide a sufficient length to the second separation section 33 to allow the flow to settle into a tranquil mode of flow after the hydraulic jump 36. It is also possible that air or gas bubbles will be mixed into the liquid at the hydraulic jump. Such bubbles are, however, large and they will easily and quickly rise to the surface, as the centrifugal gas separation continues along the second separation section 33. Typical preferred positions of the transition ring may thus be between 10 % and 80 % of the distance from the inlet end to the outlet end of the gas separation surface.

The second separation section 33 may be cylindrical or it may have a more distinctly conical form. The gas separation surface of said second gas separation section 33 may be equipped with bumps or other means disturbing the flow (see Fig. 3c) so that new hydraulic jumps occur if the flow speed tends to accelerate beyond a tranquil mode of flow. Such might be the case if so much liquid is drawn through outlet 28 that the depth of the fluid layer after transition ring 35 tends to decrease and the axial flow speed consequently to accelerate.

In the embodiment according Fig. 2 a chemical reactor indicated by a general reference 40 comprises a reactor vessel 42 with a primary reagent inlet 44, a reaction chamber 46 inside the reactor vessel 42 and a product outlet 48. Inside said reaction chamber 44 there is a rotatable centrifuge 112

with an inlet 114 for the fluid reagent mixture to be degassed. At the inlet end there is a centrally located conical reagent distribution means 120. Said centrifuge 112 is supported and rotatable by means not shown.

The central portion of the centrifuge 112 forms an elongated tubular gas separation part 130, the wall of which provides a large separation surface. The gas separation part 130 is split into a first separation section 131 and a second separation section 133 by means of a transition ring 135. The gas separation part 130 is sufficiently long, for allowing sufficient time and space for the fluid fed through inlet 114 and deposited at the separation surface by means of the distribution means 120, to settle at said separation surface and for any gas enclosed during this settling to separate.

During use a fluid layer 134 of the reagent forms on the surface of the first separation section 131. Due to viscosity the liquid layer is gradually accelerated to have approximately the same peripheral speed as the centrifuge 112 and due to gravity it is also accelerated vertically, reaching an axial velocity in the rapid flow range. Similarly, as described in connection with Fig. 1 above, the transition ring 135 will cause a hydraulic jump 136 to occur. After the hydraulic jump, the inner surface of the liquid layer in the second separation section 133 will take a conical shape, the conicity of which is determined by the ratio between centrifugal acceleration and gravity.

Similarly, as described above, the rotation of the centrifuge 112 will cause the gas entrained in the reagent to move to the central gas column 138 and further to be discharged, passing the distribution means 120.

At its bottom end the centrifuge 112 has a rotating bottom plate 118 and located close thereto one or more openings 128 functioning as reagent transfer means for allowing the reagent

to flow from the gas separation part 130 to the reaction chamber 46. During use the rotation of the centrifuge 112 will cause a mixing in said reaction chamber 46 causing the reagent components to mix as required for the desired reaction. The thickness of the liquid layer at the transfer means 128 will be in balance with the centrifugal forces caused by the rotation of the centrifuge 112 and the pressure in the reaction chamber 46.

Fig. 3a shows an embodiment of the invention wherein the transition means 35a has the shape of an annular step. The sudden deepening of the liquid layer will slow down its flow speed and cause a hydraulic jump to take place. The diameter of the centrifuge increases at the step 35a and this further increases the depth of the liquid layer and thus decreases the axial flow velocity. In certain instances this may provide a useful reserve, minimizing the risk for repeated acceleration to rapid flow.

In Fig. 3b the transition means 35b has the shape of an annular jump combined with a step, whereby the liquid flow is turned toward the center of the centrifuge forcing the hydraulic jump to take place. This shape of transition means obviously functions also without the step, i.e. with a constant centrifuge diameter before and after the jump.

As shown in Fig. 3c, the transition means may also be made of a plurality of obstacles, such as bumps, grouped to form a transition line or a transition area. The obstacles, interfering with each other cause the hydraulic jump to occur and, consequently, stabilize the flow.

Figs. 3a, 3b and 3c show examples of alternative transition means defining the position of the hydraulic jump. The transition steps of Figs. 3a and 3b may, for instance, be placed very close to the inlet end of the centrifuge making the first separation section extremely short. In such an

embodiment the actual gas separation will take place after the hydraulic jump in the second separation section at a tranquil mode of flow.

There are many other shapes and forms of transition means for defining and stabilizing hydraulic jumps, as a person skilled in the art will appreciate, and it is clear that the present invention is not limited to the shown embodiments, which are intended only as illustrations of the invention.

Fig. 4 shows another embodiment of the present invention which may be used in combination with pumping or with mixing of a reagent in a reactor, or otherwise for separating a fluid and gas. In this embodiment the centrifuge 212 is of a conical shape, causing the fluid to accelerate axially in the first separation section 231. The transition ring 235 is followed by a conical second separation section 233 with further transition means or obstacles 236 similar to those explained under Fig. 3c above.

During use the further transition means 236 will cause a new hydraulic jump to occur as soon as the flow accelerates to exceed the critical speed for tranquil flow. These hydraulic jumps will by nature be undular, whereby a re-mixing of gas into the liquid is avoided.

The above embodiments disclose centrifuges with rotating bottom plates and peripheral outlets of the liquid. It is, however, also possible to design an embodiment without a bottom plate, where the flow of liquid will be more or less free out of the centrifuge. In this case it is preferred to provide an annular shoulder at the end of the separation part to provide a damming up of the liquid flow. The centrifuge may also have more than one outlet for the separated liquid along the separation part.

According to the process of the preferred embodiment of the present invention a mixture of gas and liquid is separated into an essentially gas-free liquid and an essentially liquid-free gas. The liquid is a low or medium viscosity liquid like water, solvents, reagents, oil or the like and the gas is air or another gas substantially lighter than the liquid component of the mixture. The liquid may also contain fibers or impurities such as ink particles to an amount, which does not, however, make the fluid mixture excessively viscous.

Although the preferred embodiment of the present invention relates to achieving an essentially total separation of gas and liquid when pumping the liquid, it is seen that the apparatus will also provide great advantages in processes where separation of a gas from a liquid is required without the need for pumping. It is obvious for the persons skilled in the art that the separator can be used for many other purposes when gas is to be removed from a liquid, or a liquid containing gas is to be pumped substantially free of gas.

Claims

1. Apparatus for separating a gas from a mixture containing liquid and gas, comprising a centrifuge (12; 112, 212) with a fluid inlet (14; 114) at one end, a liquid outlet (28; 128) at the opposite end and a gas outlet (27) from the center (38; 138) of said centrifuge, c h a r a c t e r i z e d in that an inner wall of said centrifuge (12; 112; 212) forms a gas separation part (30; 130; 230) between said fluid inlet (14; 114) and said liquid outlet (28; 128), which gas separation part is divided into a first substantially cylindrical or conically widening separation section (31; 131; 231) and a second substantially cylindrical or conically widening separation section (33; 133; 233) by circumferential transition means (35; 135; 235) extending inwardly towards the center of said centrifuge (12; 112; 212) for effecting a hydraulic jump in the axial flow of the fluid and/or liquid.

2. An apparatus according to claim 1, wherein said transition means has the configuration of a protruding annular ring (35; 135), an annular protusion and step (35a), circumferentially arranged obstacles (35b; 236), or the like.

3. An apparatus according to claim 1 or 2, wherein said transition means (35; 135) has a streamlined form in the upstream direction and rises above the level of said first gas separation part (31; 131; 231) to a height which is no more than about 1/20, preferably no more than about 1/40 of the diameter of said first gas separation part.

4. An apparatus according to claim 1, 2 or 3, wherein said centrifuge (12; 112) has an elongated tubular configuration.

5. An apparatus according to claim 4, wherein said first separation section (31) is substantially cylindrical and said second separation section (33) widens conically towards the outlet end of said centrifuge (12).

6. An apparatus according to any one of the preceding claims, wherein said separation part (30; 130; 230) is elongated for providing essentially complete separation of said gas from said fluid, and said second separation section (33; 133; 233) has a sufficient length for allowing any gas bubbles enclosed at the hydraulic jump to be removed from the liquid.

7. An apparatus according to any one of the preceding claims, wherein said transition means (35; 135; 235) divides said gas separation part (30; 130; 230) in such a way that the axial length of said gas separation part to the axial length of said second separation part (33; 133; 223) is between 1:0.1 and 1:0.9, preferably between 1:0.2 and 1:0.8, most preferably between about 1:0.4 to 1:0.6.

8. An apparatus according to claim 6, wherein said second separation section (233) is provided with further transition means (236) for maintaining a tranquil flow with a Froude number < 1 in said second separation section (233).

9. An apparatus according to any one of the preceding claims, wherein the diameter of the outlet end of said centrifuge (12) is significantly enlarged to form a centrifugal pumping wheel (24), preferably enclosed in a stationary pump housing (16).

10. An apparatus according to any one of the preceding claims, wherein the inlet end of said centrifuge (12, 112) is provided with fluid distribution means, such as peripheral blades (20), a central spreading funnel (120) or the like.

11. An apparatus according to any one of the preceding claims, wherein said outlet end of said centrifuge (12; 112) comprises a rotating bottom plate (18; 118).

12. A process for the separation of gas from a fluid mixture containing liquid and gas, comprising the steps of:

- feeding said fluid mixture into one end of a rotating centrifuge,
- causing said mixture to flow in a rapid axial flow mode with a Froude number (Fr) > 1 in a thin fluid layer along a gas separating surface formed by a wall of said centrifuge;
- causing said fluid flow to pass over a circumferential discontinuity in said wall of said centrifuge and thereby providing a transition in said flow from said rapid flow with Fr > 1 to a tranquil flow with Fr < 1 via a hydraulic jump (36; 136);
- allowing said fluid to flow in a tranquil axial flow mode with Fr < 1 towards the opposite end of said centrifuge;
- allowing said gas to separate from said liquid before and after said discontinuity and to collect in the center of said centrifuge; and
- discharging the resulting degassed liquid from said opposite end and said gas from said center of said centrifuge.

13. A process according to claim 12, wherein said liquid is discharged centrifugally at a pumping pressure from the periphery of said opposite end of said centrifuge.

Fig 1

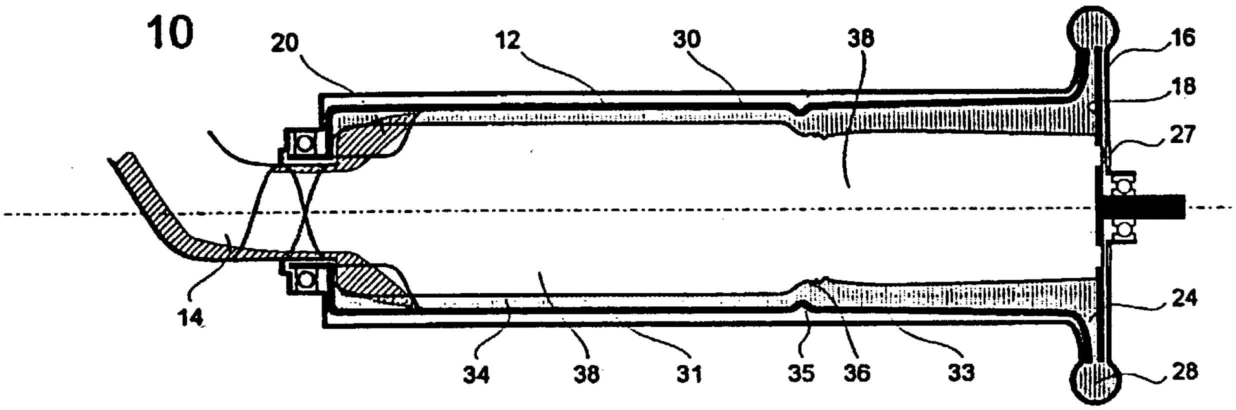
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Fig 2

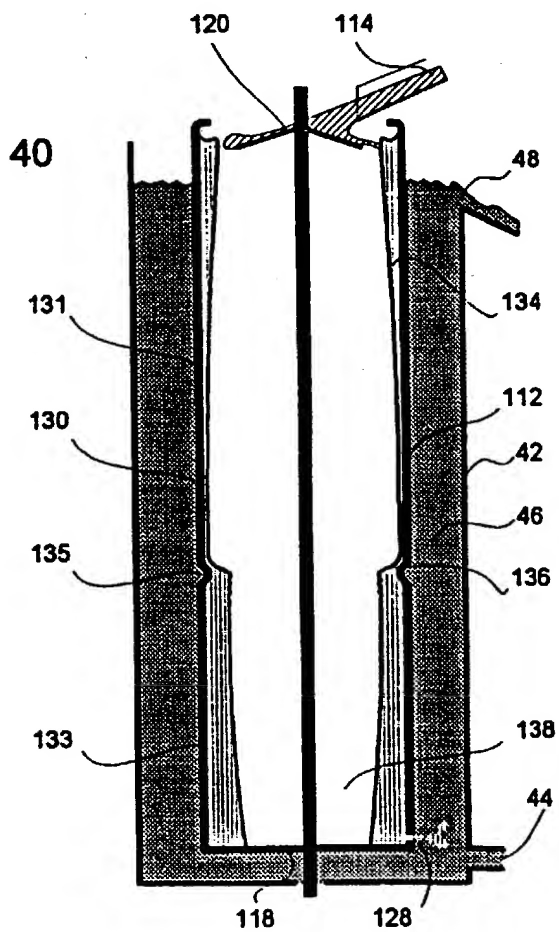
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Fig 3a

Fig 3b

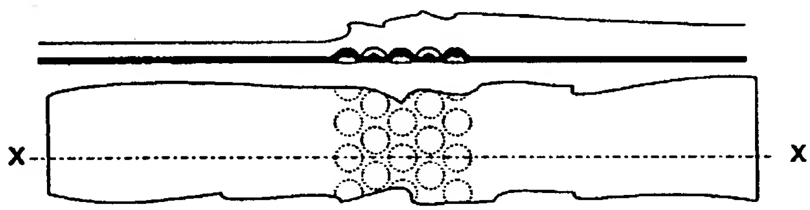
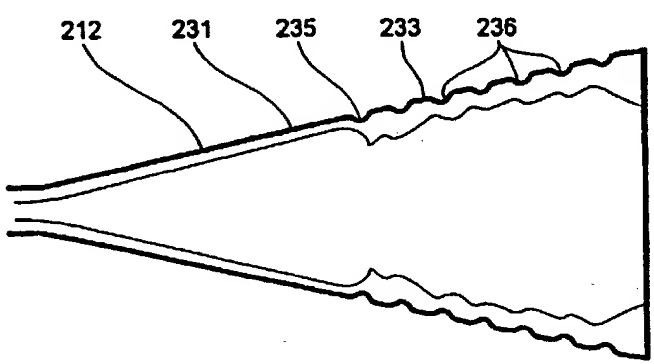


Fig 4



INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 95/00703

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: B01D 19/00, B04B 1/00 // D21D 5/26, F04D 7/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: B01D, C02F, D21D, F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DIALOG, WPI, CLAIMS, PAPERCHEM, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4600413 A (KENNETH B. SUGDEN), 15 July 1986 (15.07.86), column 3, line 28 - column 4, line 59; column 6, line 34 - column 4, line 37, figure 1 --	1,4,12
Y	US 4056371 A (R. BERTRUM DIEMER, JR. ET AL), 1 November 1977 (01.11.77), column 5, line 53 - column 6, line 9, figure 2 --	1,4,12
A	US 5182031 A (JEAN-PIERRE LAMORT), 26 January 1993 (26.01.93), column 3, line 14 - line 31; column 3, line 59 - line 62, figure 1 -- --------	1-13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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